Basic Example of Applying Effective Component Selection Method

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Abstract
When designing electronic circuits from discrete components, the finite number of component values in E series of preferred numbers is the limiting factor. For example, the E24 series contains just 24 component values per decade. If accuracy of the proposed circuit is required, use of E series of preferred numbers becomes limiting. The exact calculated value of the component must be rounded to the nearest value in the E series. This rounding creates the error of the proposed circuit parameters. For example, if an electronic filter needs to be designed, it will be out of tuning due to inaccurate part rounding. This paper deals with the error reduction. The error is caused by the necessity to use components from the E series of preferred numbers. The newly designed Effective Component Selection Method is used to minimize this error. The method works on the principle of multiple-stage optimization. The Effective Component Selection Method is applied on a very simple circuit, to design 21 different RC low pass filters. For comparison, rounding to the nearest value in the series method is also applied on the same example of the RC low pass filters design. The RC low pass filter's corner frequency f_{cor} was chosen to be the filter's precision criterion. The results achieved by both methods were compared. The error of the designed circuit is calculated as the standard deviation of the difference between the wanted value and the resulting value. Compared with the Rounding to the nearest value in the series method, the Effective Component Selection Method reduces the error by 6 times.

Abstrakt
Při návrhu elektronických obvodů z diskrétních součástek je omezujícím faktorem konečný počet hodnot součástek ve vyráběných řadách. Například řada E24 obsahuje pouze 24 hodnot součástek na dekádu. Je li požadována přesnost navrhovaného obvodu, je nutnost použít hodnoty součástek z dostupné vyráběné řady limitující. Přesná vypočtená hodnota součástky musí být zaokrouhlena na nejbližší hodnotu z řady. Toto zaokrouhlení vytváří chybu parametrů navrhovaného obvodu. Jedná li se například o návrh elektronického filtru, filtr bude kvůli nepřesnostem součástek rozladěn. Článek se zabývá snižováním chyby způsobené nutností použít součástky z vyráběné řady. Pro minimalizaci chyby je použita nově navržená Metoda efektivního výběru součástek. Metoda pracuje na principu několika stupňové optimalizace. Metoda efektivního výběru součástek je aplikována na velmi jednoduchý obvod – výpočet 21 různých RC článků dolní propusti. Pro porovnání je na stejný příklad návrhu dolní propusti aplikována i metoda zaokrouhlování na nejbližší hodnotu v řadě. Kritériem přesnosti byl zvolen zlomový kmitočet f_{cor} dolní propusti. Výsledky obou metod byly porovnány. Metoda efektivního výběru součástek snižuje chybu navrhovaného obvodu. Chyba navrhovaného obvodu je počítána, jako směrodatná odchylka z rozdílů chtěné hodnoty a výsledné hodnoty. V porovnání s metodou zaokrouhlování na nejbližší hodnotu v řadě Metoda efektivního výběru součástek 6 krát snižuje chybu.

INTRODUCTION

When designing an electric circuit from discrete components with precise parameters, design accuracy is limited by the series production preferred values, such as the frequently used E24 series. In the development, the exact value of a discrete component is calculated, but this value is not available in the E series. Therefore, the closest possible value is selected, which is a number of E series. Essentially, the exact value of a component is rounded to the E series of components.

This rounding creates an error; the component value will be inaccurate. Therefore, the resulting function of the circuit will be inaccurate. For example, if it is an analog filter, the filter may be out of tune.

Rounding to the nearest value in the series method is used by computational tools for filter design [2], [3] and [4]. One of the solutions used to minimize this error is the use of custom-made components, but this solution is expensive. It is also possible to use a higher E series of components, but higher E series of capacitors and inductors are difficult to access. It is

also possible to assemble components from serial and parallel components connections, but this solution multiplies the number of components on the printed circuit board, thus the PCB space and cost increases. This article shows how to use
the Effective Component Selection Method to solve these problems.
21 RC low pass filters were chosen as a basic example to demonstrate the design accuracy in this paper. The 21 RC filters corners frequencies are tuned every 20 Hz. One of this RC filters is shown in Fig. 1.

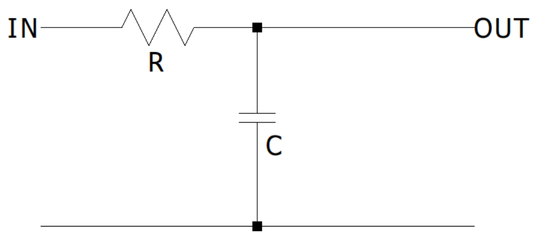

Fig. 1 RC low pass filter

The requirement is to design the corners frequencies f_{cor} as accurately as possible. The corner frequency calculation is determined by formula (1).

$$f_{cor} = \frac{1}{2 \cdot \pi R C} \quad (1)$$

In the Rounding to the nearest value in the series method uses substitution of the desired corner frequency and selected capacity value into the adjusted formula (2).

$$R = \frac{1}{2 \cdot \pi f_{cor} \cdot C} \quad (2)$$

This formula results is an accurate resistance value. This resistance value is not available in the E24 series, therefore the closest E24 series value must be selected.
For example, f_{corwa} 1020 Hz is wanted corner frequency and C 100 nF capacity. The formula gives an exact resistance value R_{ex} of 1560.34 Ω. The nearest value of the resistor from E24 series is chosen, which is R_{ch} 1K6, but this rounding results in an error, and so the resulting filter corner frequency is f_{corre} 994.71 Hz. Thus, the difference between the resulting frequency and the wanted frequency is $f_{ERRORrn}$ - 25.28 Hz. Selected values used in the Rounding to the nearest value in the series method are presented in Tab. 1.
From the table it can be observed that frequency tuning error due to rounding to the E24 series can be large. this error can degrade the device's functionality.

Tab. 1: Rounding to the nearest value in the series method

f_{corwa}	f_{corre}	$f_{ERRORrn}$	C	R_{ex}	R_{ch}
1020	994.71	-25.28	100n	1560.34	1K6
1040	1061.03	21.03	100n	1530.33	1K5
1060	1061.03	1.03	100n	1501.46	1K5
1080	1063.86	-16.13	22n	6698.44	6K8
1100	1063.86	-36.13	22n	6576.65	6K8
1120	1184.18	64.18	56n	2537.54	2K4
1140	1166.82	26.82	22n	6345.89	6K2
1160	1166.82	6.82	22n	6236.47	6K2
1180	1166.82	-13.17	22n	6130.77	6K2
1200	1236.63	36.63	3n9	34007.46	33K
1220	1236.63	16.63	3n9	33449.96	33K
1240	1300.28	60.28	1n8	71305.97	68K
1260	1224.26	-35.73	10n	12631.34	13K
1280	1236.63	-43.36	3n9	31881.99	33K
1300	1300.28	0.28	1n8	68014.93	68K
1320	1300.28	-19.71	680p	177311.6	180K
1340	1300.28	-39.71	680p	174665.2	180K
1360	1326.29	-33.70	1n2	97521.41	100K
1380	1326.29	-53.70	1n2	96108.05	100K
1400	1457.46	57.46	1n2	94735.08	91K
1420	1462.82	42.82	680p	164824.9	160K

METHODS

The Effective Component Selection Method runs on principle of optimization. The first step in this method is finding a suitable degree of freedom. The degree of freedom is the value of the component selected at the beginning of the calculation as a constant against which the values of the other components are calculated. In this case, the value of capacity C (degree of freedom) was chosen for exact resistance value calculation (3).

$$R_{ex} = \frac{1}{2 \cdot \pi \cdot f_{corva} \cdot C} \qquad (3)$$

Next, the numbers are substituted into the formula and the exact value of the other components is calculated.
For example, the filter with a corner frequency 1020 Hz and a capacitor C 120nF. Resulting exact resistance value R_{ex} is 1300.28 ohm. The neighboring resistor values from the E24 series are now found. The neighboring resistors are 1K3 and 1K5. The proposed parameter error is calculated as the difference between the calculated frequency (4) and the wanted frequency (5) .

$$f_{corre} = \frac{1}{2 \cdot \pi \cdot R \cdot C} \qquad (4)$$

$$f_{ERRORef} = F_{corre} - F_{corwa} \qquad (5)$$

The error for the 1K3 resistor is 0.22 Hz, the error for the 1K5 resistor is 135.80 Hz. Select the resistance value with the lowest absolute value error. The part with the lowest absolute value error is 1K3. If the proposed circuit is described by more formulas, the circuit is more complex and needs more components. In this case, it is necessary to make a combination of all the possibilities of selected neighboring components and select the rigid combination with the lowest proposed parameter error $f_{ERRORef}$. The entire previous calculation is performed for each value of the degree of freedom C. The error is calculated for each combination with different degree of freedom C. All errors are matched and the combination of components C_{sel} and R_{ch} with the lowest error is selected. This calculation runs in a cycle as long as all errors for all the values degrees of freedom are calculated. The calculation procedure for one of the filters is shown in Tab. 2.

Tab. 2: Error calculation

f_{ERROR}	-49.54	-25.28	0.22	41.03
C_{sel}	82n	100n	120n	150n

Tab. 2: Error calculation

f_{ERROR}	43.86	6.14	6.14
C_{sel}	220n	330n	470n

This combination is the output of
the Effective Parts Selection Method.

RESULTS

This calculation was performed for 21 RC low pass filters using the Effective Component Selection Method and the Rounding to the nearest value in the series method. Error standard deviations were calculated for both methods, and histograms plotted (Fig. 2, Fig. 3). Tab. 3 shows the results of the Effective Component Selection Method. They include frequencies, errors and components values. The Effective Component Selection Method's error standard deviation is σ_{ef} = 6.2. Rounding to the nearest value in the series method's error standard deviation is σ_{rn} = 36.9.
The Effective Component Selection Method noticeably increases the proposed circuit's accuracy.

Tab. 3: Effective Component Selection Method

f_{corwa}	f_{corre}	$f_{ERRORef}$	C	R_{ex}	R_{ch}
1020	1020.22	0.22	120n	1300.28	1K3
1040	1026.14	-13.85	330n	463.73	470
1060	1061.03	1.03	100n	1501.46	1K5
1080	1078.28	-1.71	18n	8186.98	8K2
1100	1105.24	5.24	120n	1205.71	1K2
1120	1121.59	1.59	330n	430.61	430
1140	1133.58	-6.41	39n	3579.73	3K6
1160	1155.80	-4.19	27n	5081.57	5K1
1180	1178.92	-1.07	18n	7493.17	7K5
1200	1205.71	5.71	12n	11052.42	11K
1220	1224.26	4.26	10n	13045.48	13K
1240	1236.63	-3.36	3.3n	38894.16	39K
1260	1254.17	-5.82	27n	4678.27	4K7
1280	1291.84	11.84	2.2n	56518.09	56K
1300	1300.28	0.28	1.8n	68014.93	68K
1320	1326.29	6.29	12n	10047.66	10K
1340	1339.68	-0.31	3n3	35991.61	36K
1360	1360.29	0.29	3n	39008.56	39K
1380	1370.84	-9.15	2n7	42714.69	43K
1400	1410.94	10.94	4n7	24187.68	24K
1420	1421.02	1.02	560p	200144.5	200K

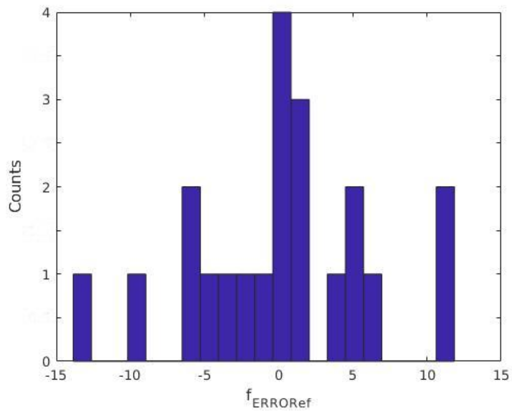

Fig. 2: Error histogram of Effective Component Selection Method

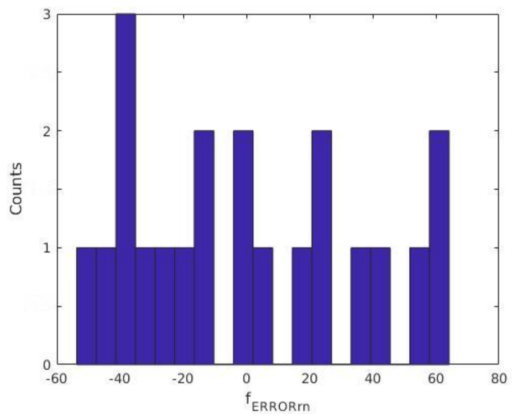

Fig. 3: Error histogram of Rounding to the nearest value in the series method

CONCLUSION

Simple test example of designing 21 RC low-pass filters demonstrated the efficiency of the Effective Component Selection Method compared to the Rounding to the nearest value in the series method. The Effective Component Selection Method reduced the circuit error by 6 times compared to the Rounding to the nearest value in the series method that is used by the filter design computational tools.

The advantage of the Effective Component Selection Method is that component parts do not need to be assembled from serial and parallel combinations for accuracy increasing. Therefore, it saves PCB space and production costs.

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